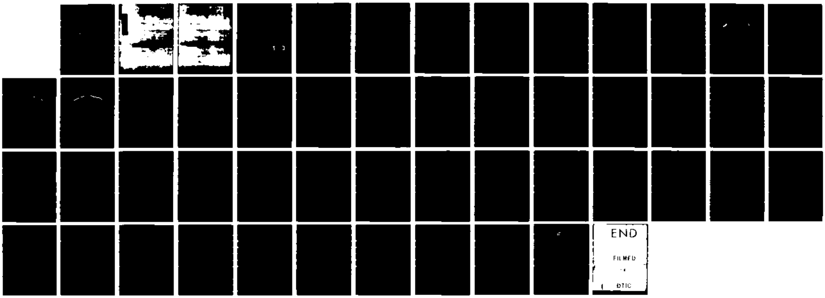
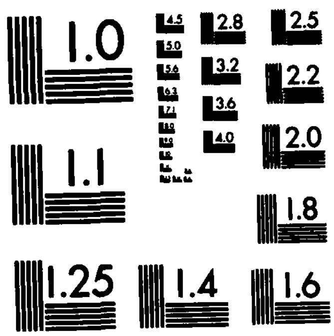
AD-A123 252 A GLOBAL CALIBRATION TECHNIQUE IN USE AT THE ETS(U) 1/1
MASSACHUSETTS INST OF TECH LEXINGTON LINCOLN LAB
R C RAMSEY ET AL. 08 NOV 82 ETS-66 ESD-TR-82-095
UNCLASSIFIED F19628-80-C-0002 F/G 3/1 NL






technique

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

A GLOBAL CALIBRATION TECHNIQUE IN USE AT THE ETS

R.C. RAMSEY
A.A. MATHIASEN
J.H. DIAL
R.L. IRELAN
Group 94

PROJECT REPORT ETS-66

8 NOVEMBER 1982

Approved for public release; distribution unlimited.

LEXINGTON MASSACHUSETTS

ABSTRACT

This report describes the installation and results of a global calibration program introduced for both telescopes at the Lincoln Laboratory Experimental Test Site. The uncorrected positional pointing errors, due primarily to tube flexure, sag and astronomical refraction, were found to be as high as ten arc minutes at low (twenty degrees) elevation angles. The calibration is performed by a software program which contains look-up tables, for each telescope, that represent ten-degree increments of azimuth and elevation. Residual errors are now less than one arc minute except for a narrow zone across the northern sky. This is a region where there was a high gradient in the uncorrected errors and the residuals here, after correction, are a maximum of three arc minutes. This technique has remained stable over the past year.

TABLE OF CONTENTS

I. INTRODUCTION

The 31-inch telescopes at the Lincoln Laboratory Experimental Test Site (ETS) exhibit pointing errors due to sag and flexure and astronomical refraction. Pointing errors of up to 10 arc minutes have been observed when the telescopes are directed at low elevations after initial zero point calibration at the zenith. This has never presented a particular problem to operations at ETS, primarily because the field of view, even in the zoom mode, is much larger than the size of these pointing errors. Also these errors do not enter into the positional data obtained on the positions of objects since nearby stars only a degree or so away from the object are used in this measurement. Global calibration has been discussed previously[1] and possible solutions suggested but never seriously undertaken.

Recently some tests have begun on the use of the ETS system to prove the feasibility of daylight tracking of satellites. These pointing errors now present a major problem to this type of tracking. The experimental vidicon cameras used have a much smaller format, namely one quarter of the 80 mm format of the Ebiscon camera tube used at ETS.

During the past year an attempt has been made to determine the magnitude and stability of the pointing errors and to prove the practicality of the use of a "Real Time" correction program to eliminate or at least greatly reduce them.

II. INITIAL ERROR DETERMINATION

A. Procedure

Each telescope was separately investigated. The procedure used was to calibrate at the zenith and then to move to a particular azimuth and elevation, call up a nearby calibration star, and measure the distance from boresight to this star. Fortunately, the real time operating system (RTS)[2] already includes the software to do this. The single star calibration procedure calls up a calibration star and after the star is manually moved to boresight and positional data are obtained, the distance between the boresight location and the star's location is printed out in terms of declination (δ) and right ascension multiplied by the cosine of declination $[\alpha\cos(\delta)]$. The latter dimension is actually horizontal on the monitor with the vertical dimension corresponding to the declination.

At first it was thought necessary to move to the various locations around the sky in a near-random fashion, since the pointing error might be influenced by the method by which the telescope got to a particular location.

The pointing errors in telescope B were obtained first over a period of several months during the summer of 1981. Data corresponding to over a hundred azimuth and elevation settings of the telescope were obtained over a period of one or two nights. These data were repeated five times with a week or two between measurements.

It was found unnecessary to move in a random fashion around the sky. Essentially, the overall error patterns obtained for telescope B for a particular point in the sky remained the same regardless of the previous position of the telescope. In addition, it was found that the greatest positional errors were around the pole and more data points were obtained in this region and less in others as the measurements continued.

Data for telescope A were obtained in a much shorter time than that for B as this final procedure was followed.

B. Results

Figures 1 and 2 are composites of the errors measured for telescope A in the $\alpha\cos(\delta)$ and δ dimensions. Contour lines are drawn for every fifty arc seconds of pointing error. A total swing of 650 arc seconds error (100 to -550) exists in the horizontal dimension. The vertical dimension (declination) exhibits a swing of 350 arc seconds. Figures 3 and 4 show the same curves for telescope A.

(1) The region in the sky from about 310° in azimuth and 20° in elevation following a line through the pole (35°) and back to a point about 50° in azimuth and 20° in elevation is the region of greatest change (highest gradient) in pointing error. It was noted that as the telescope is commanded to move from a point south of this line to a point north of the line it actually rotates about its mount and goes from an "overslung" to an "underslung" position. Thus, the telescope presents a completely different physical configuration on one side of this line from the other.

(2) The plots for telescope A are different from those for B and show less error. The six-inch photometer is mounted on B only; this is the only basic difference in the two telescope configurations.

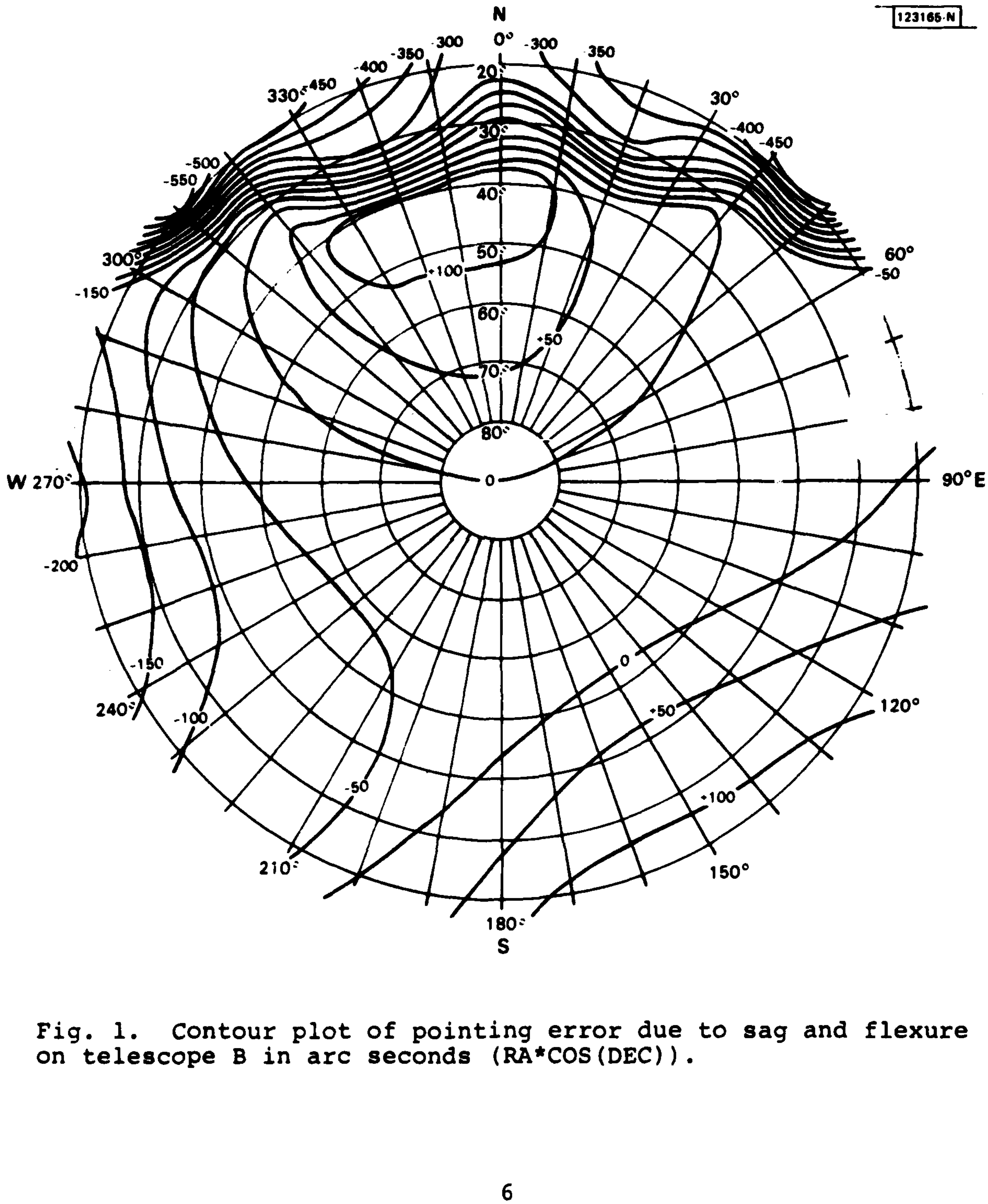


Fig. 1. Contour plot of pointing error due to sag and flexure on telescope B in arc seconds (RA*COS(DEC)).

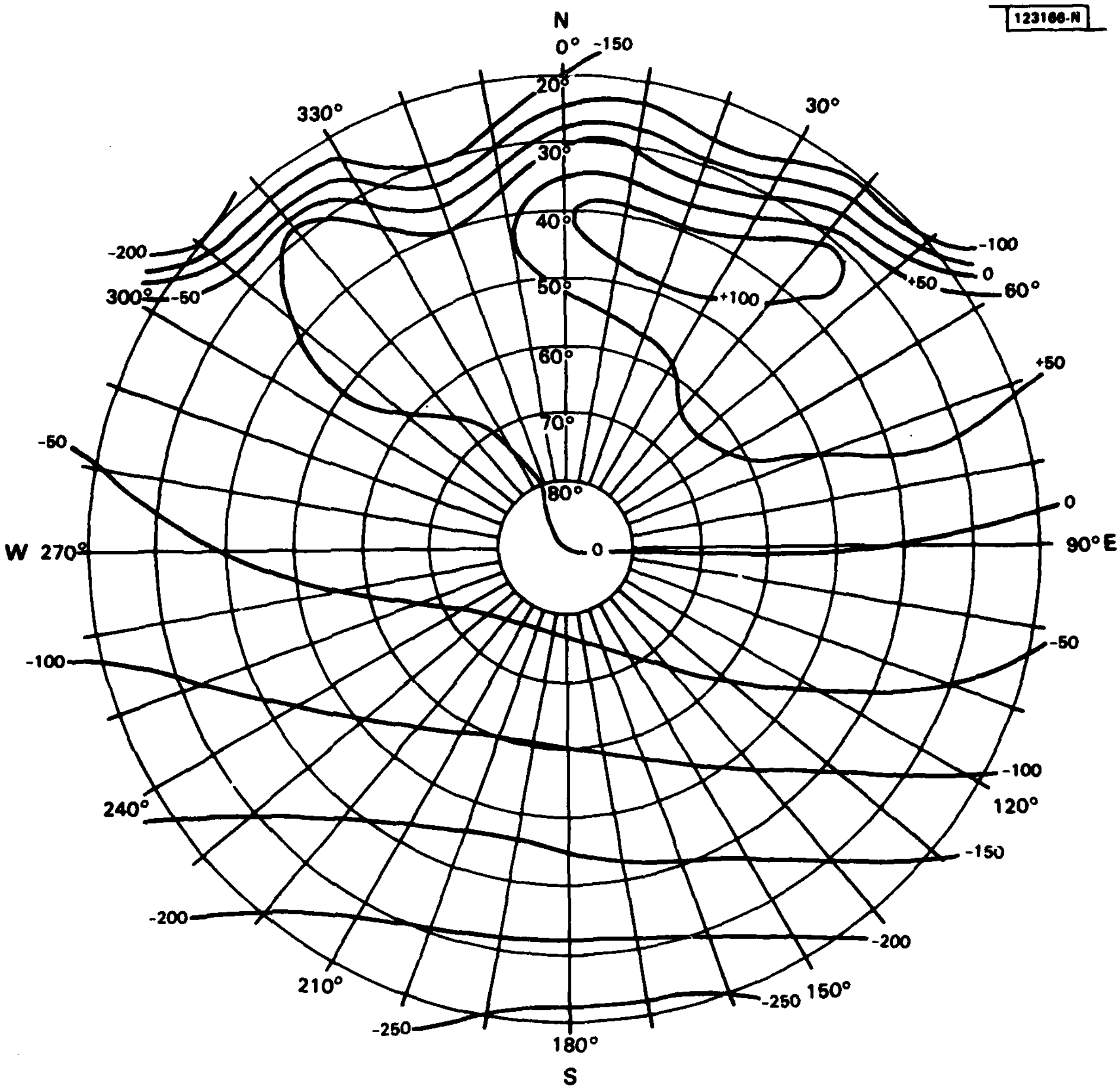


Fig. 2. Contour plot of pointing error due to sag and flexure on telescope B in arc seconds (declination).

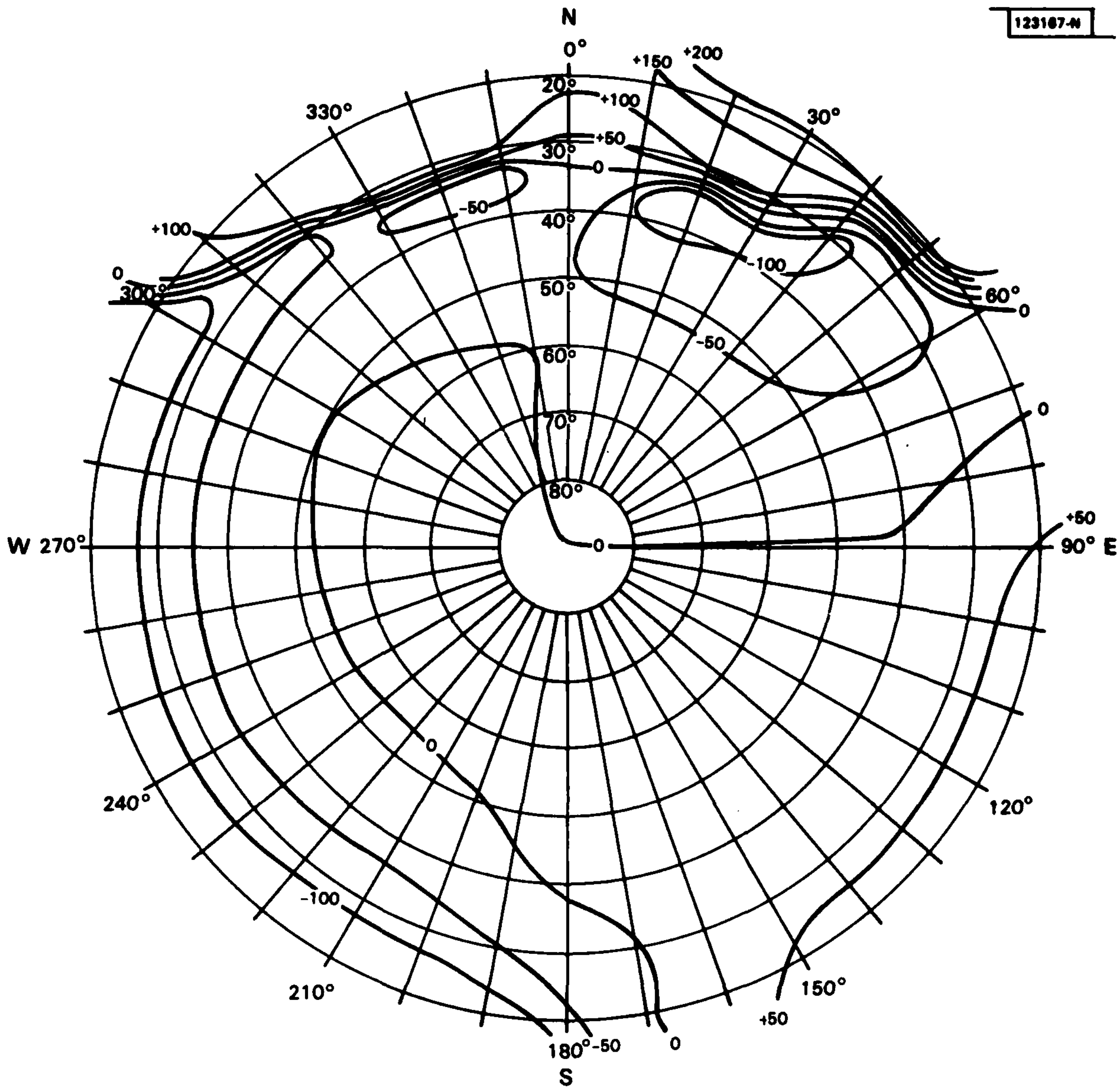


Fig. 3. Contour plot of pointing error due to sag and flexure on telescope A in arc seconds (RA*COS(DEC)).

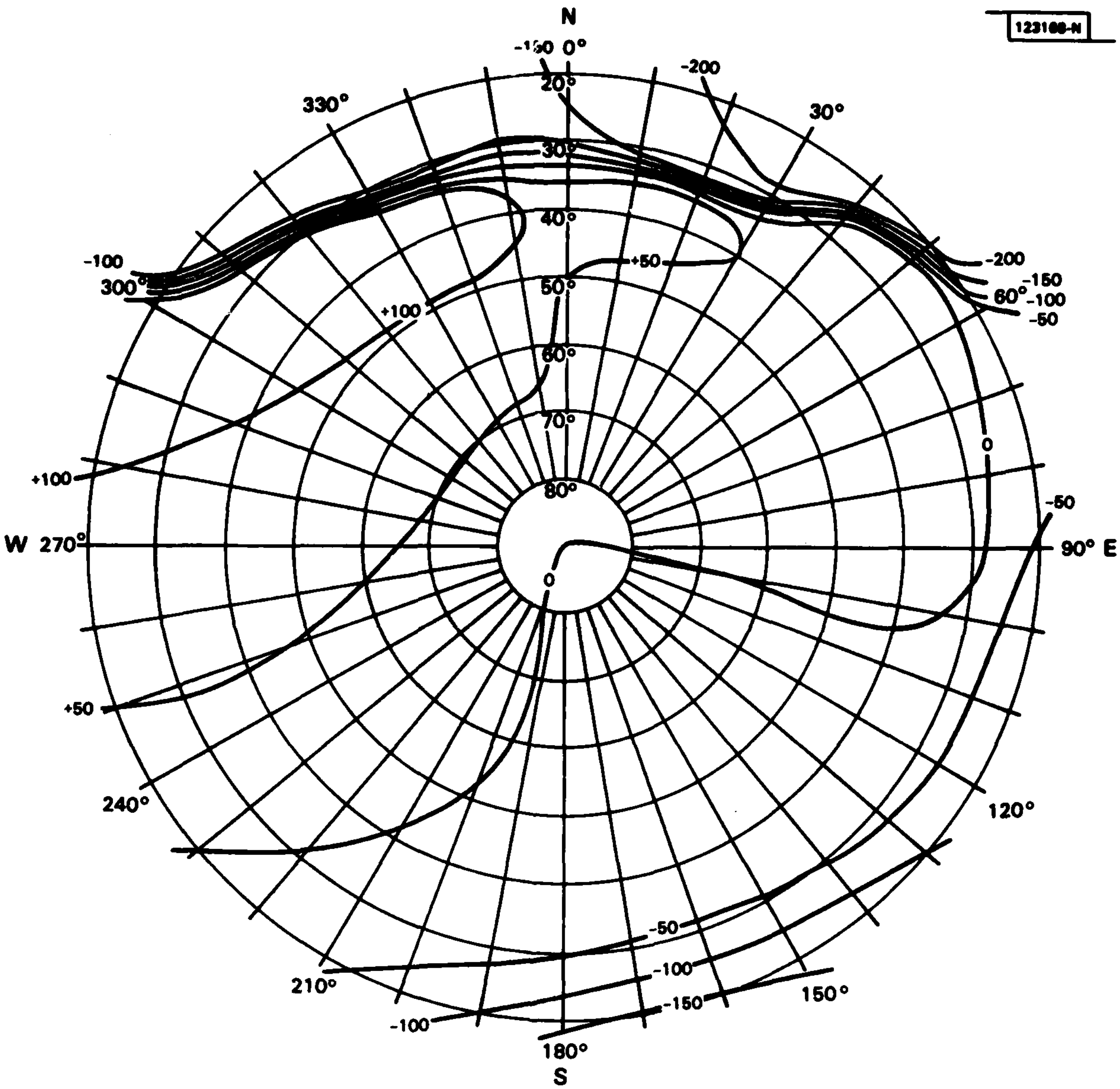


Fig. 4. Contour plot of pointing error due to sag and flexure on telescope A in arc seconds (declination)).

III. MATHEMATICS AND PROGRAM DESIGN

The original design of the telescope operating system included a correction task whose function was to modify each pointing command by a quantity computed during a global calibration run. These corrections in right ascension (or hour angle) and declination were to include all errors from whatsoever source. A series of tests showed that there was not enough stability in the telescopes to support precision measurements in this manner, so the idea was shelved, and a local calibration was substituted. As pointed out earlier, the advent of cameras with smaller fields of view made it desirable to include an error correction which would put an object within the field of view if the object were at its nominal position. A global calibration plan was revived. Experiments with a $10^{\circ} \times 10^{\circ}$ grid and linear interpolation showed we could correct to better than a desired 4', indeed in most cases to less than 1'.

The error correction for the telescope takes the form of 2 two-dimensional tables whose coordinates are azimuth and elevation and whose entries are right ascension or declination correction.

To make the programming simple, the azimuth and elevation units are 10°. We convert the telescope azimuth, A, and elevation, E, in radians to azimuth, $\hat{A}$, and elevation, $\hat{E}$, in units of 10° as follows

$$\hat{A} = \frac{18}{\pi} A$$

$$\hat{E} = \frac{18}{\pi} E$$

so we have a quick index into the table. Thus, if we look up the values of the error, e (in either right ascension or declination) at the four corners defined by $[\hat{A}]$, $[\hat{A}]+1$, $[\hat{E}]$, $[\hat{E}]+1$ (where $[x]$ is the largest integer $\leq x$), then

$$\text{Error } (\hat{A}, \hat{E}) = ([\hat{E}]+1-\hat{E}) \{([\hat{A}]+1-\hat{A}) e_{00} + (\hat{A}-[\hat{A}] e_{10}\}$$
$$+ (\hat{E}-[\hat{E}]) \{([\hat{A}]+1-\hat{A}) e_{01} + (\hat{A}-[\hat{A}]) e_{11}\}$$

where

e_{00} is the measured error at $(|\hat{A}|, |\hat{E}|)$

e_{01} at $([\hat{A}], [\hat{E}]+1)$

e_{10} at $([\hat{A}]+1, [\hat{E}])$

e_{11} at $([\hat{A}]+1, [\hat{E}]+1)$

The computed right ascension (α) and declination (δ) are corrected by these values (if the "error correction" button is on). To avoid discontinuities in this process, the tables are indexed from $\hat{A} = 0$ to $\hat{A} = 36$ and from $\hat{E} = 0$ to $\hat{E} = 9$.

The data used by the corrections task are generated by an offline task running in nonreal time. The data for that task are a source file produced by the source editor. The file consists of a matrix of the observed telescope errors in arc seconds in $\alpha\cos(\delta)$, and one in δ. The values are taken by inspection of the contour plots. These data are converted to a form usable by the corrections task and then written to a dedicated disk partition in binary form (see Appendix A). Two such binary files are resident on the partition, one for each telescope.

The data tables for the selected telescope (either "A" or "B") are read from disk into a private shared region* by an asynchronous task (GCTASK), which is activated by the corrections initialization overlay to RTS. This task is given a high priority to enable it to complete the disk accesses before the data are needed. It sets up the data, writes the header information to the line printer, then waits for some other task to insert the region before exiting the system.

*In the Max IV Operating System a private shared region is an area of actual memory which can appear in the virtual memory of many tasks simultaneously. Creation is the act of initially informing the operating system of the particulars of a specific private shared region, while insertion is a request by name to use a previously created region.

The corrections task (T4) does the insertion during the first frame of the main pointing sequence. A handshake protocol is implemented using flags in the shared region. Once the region is inserted by the corrections task, it remains in the system until this task is deestablished by RTS during the shutdown sequence.

Whether or not a pointing command is modified depends on whether or not a button, labeled ERROR CORR is pushed. When the backlight is on, error corrections are being made, otherwise no. These global error corrections are independent of any other corrections, for example, joystick-controlled manual offsets.

IV. RESIDUAL ERROR

Figures 5 through 8 show the residual errors after the correction programs were put into both A and B telescopes. These data values were obtained by again using the single star calibration program. These residual errors were printed out after use of the select and add offset buttons to reposition the calibration star on boresight.

(1) Relatively large (up to 200 arc seconds) residual errors remain in that band across the northern sky, as discussed before, where the original high gradient errors exist. This was to be expected since ten-degree increments are used for the look-up table. Perhaps, if the table were increased an order of magnitude, to one-degree increments, these residuals would be smaller. At this time, it is felt that the additional complexity involved does not warrant pursuing this effort.

(2) Beside this band of large errors, the remaining residual errors are generally much less than a minute of arc. It should be noted that every time these residual errors are investigated, or for example, from one week to the next, a different bias can be found in these errors. This is generally on the order of about half an arc minute.

The general pattern of error remains the same. This has been noted in examining the residual errors for telescope B over a period of the last five months. Telescope A correction has seemed to hold for the last month since it was just recently entered into the system.

(3) How well these corrections will hold up over a long period is not yet known. Certainly, if a major change in the physical configuration of one of the telescopes is made, it might be expected to materially affect the present pointing error patterns.

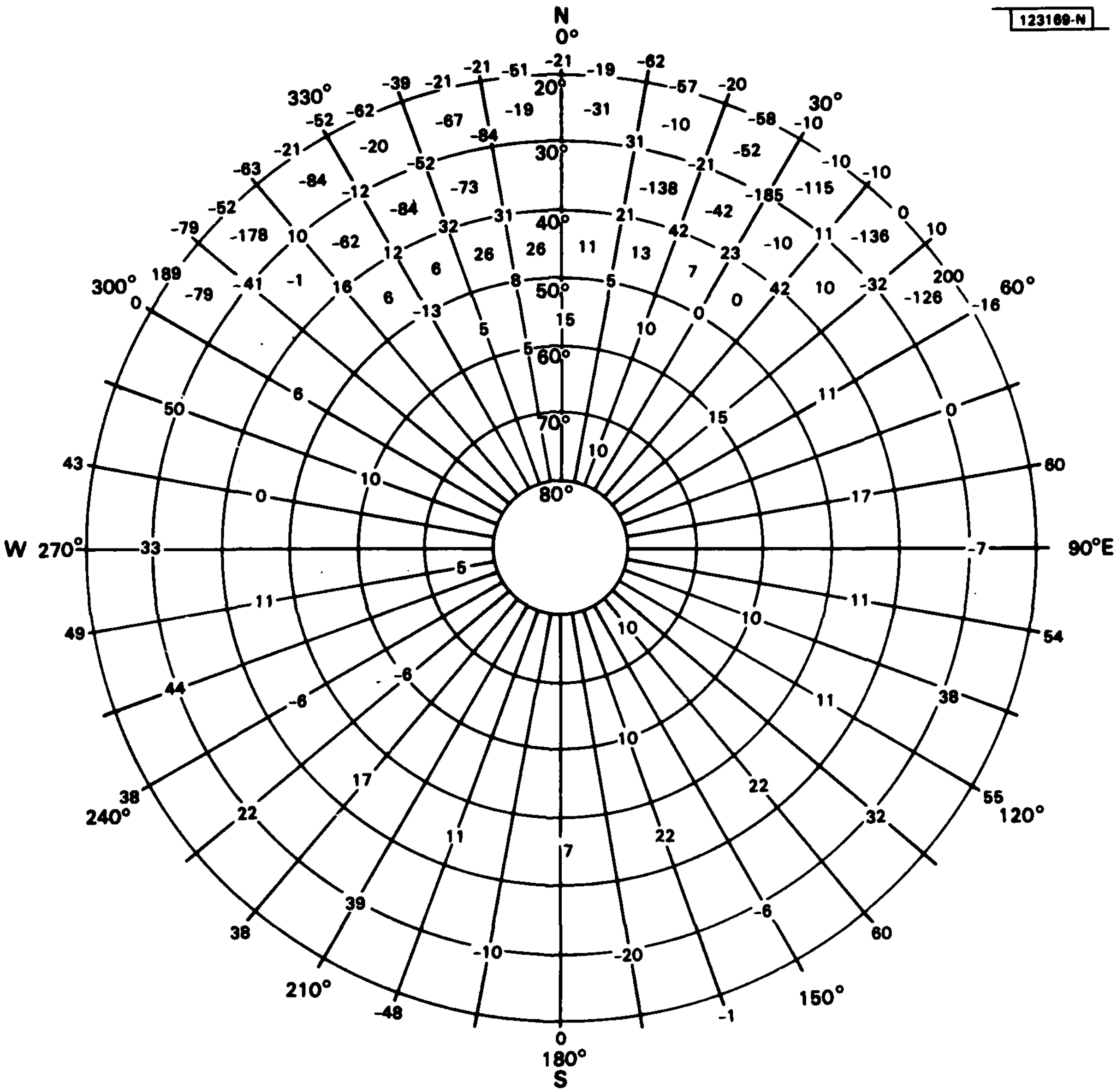


Fig. 5. Plot of residual pointing error due to sag and flexure on telescope B in arc seconds (RA*COS(DEC).

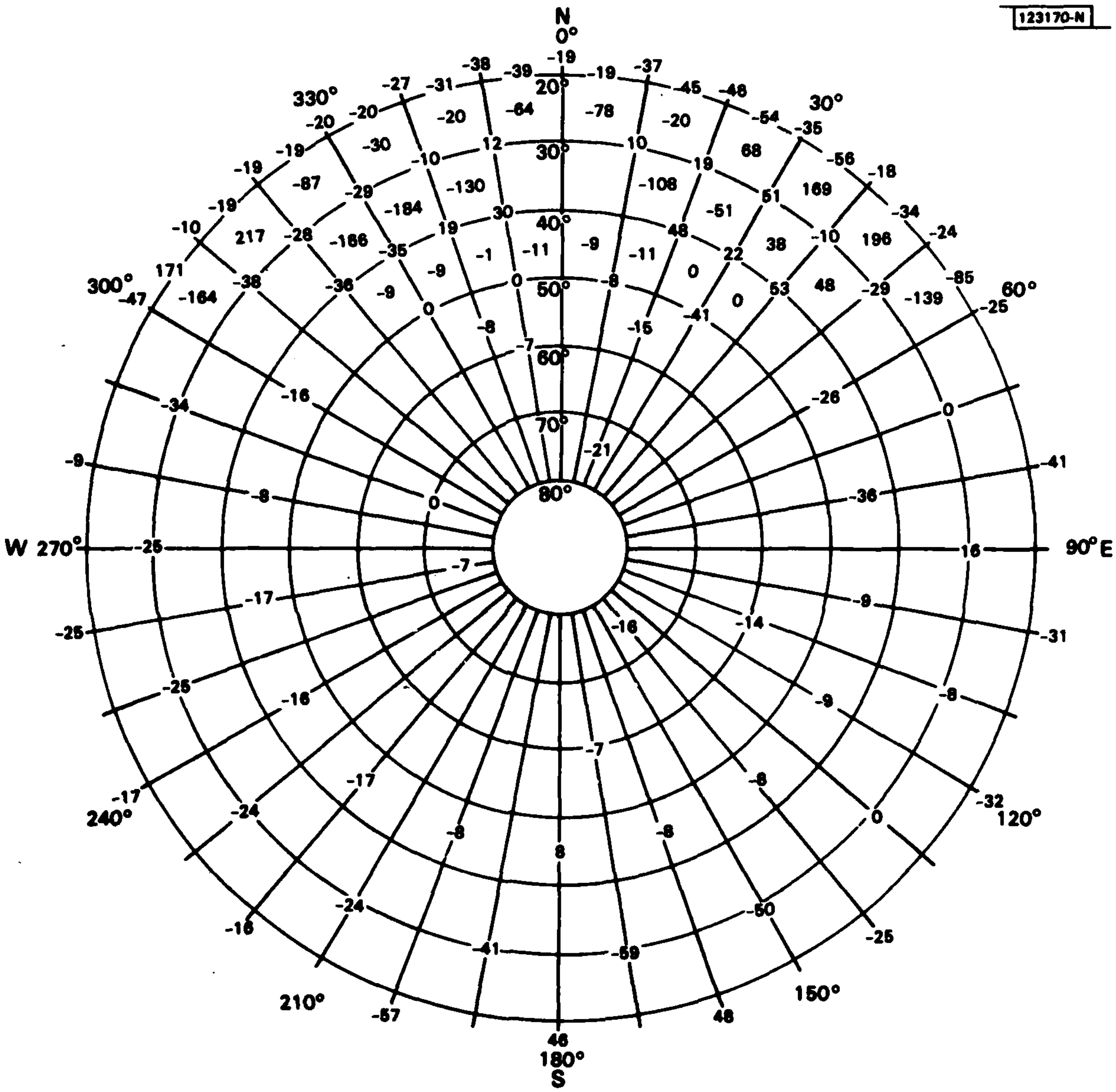


Fig. 6. Contour plot of pointing error due to sag and flexure on telescope B in arc seconds (declination).

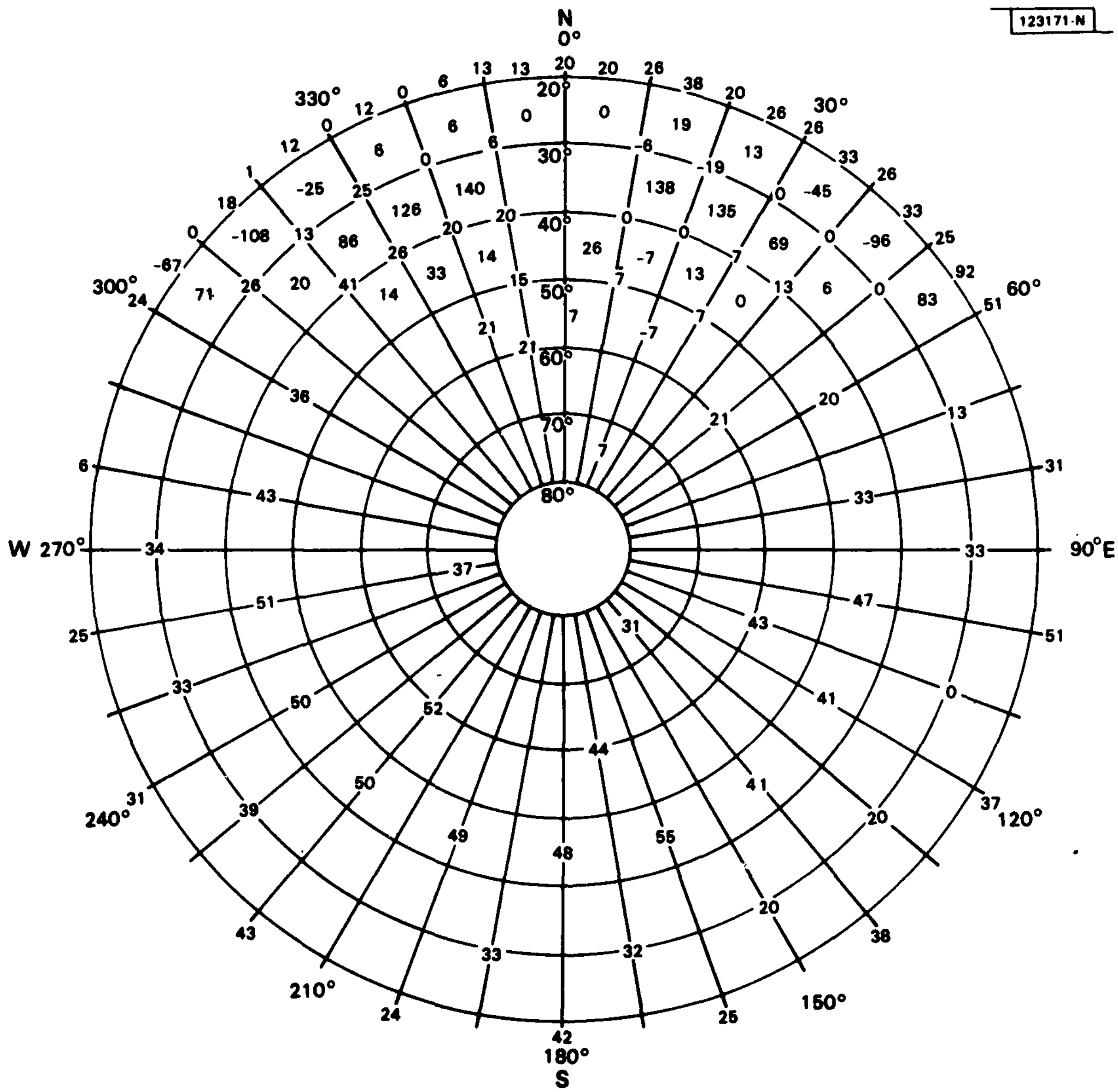


Fig. 7. Plot of residual pointing error due to sag and flexure on telescope A in arc seconds (RA*COS(DEC)).

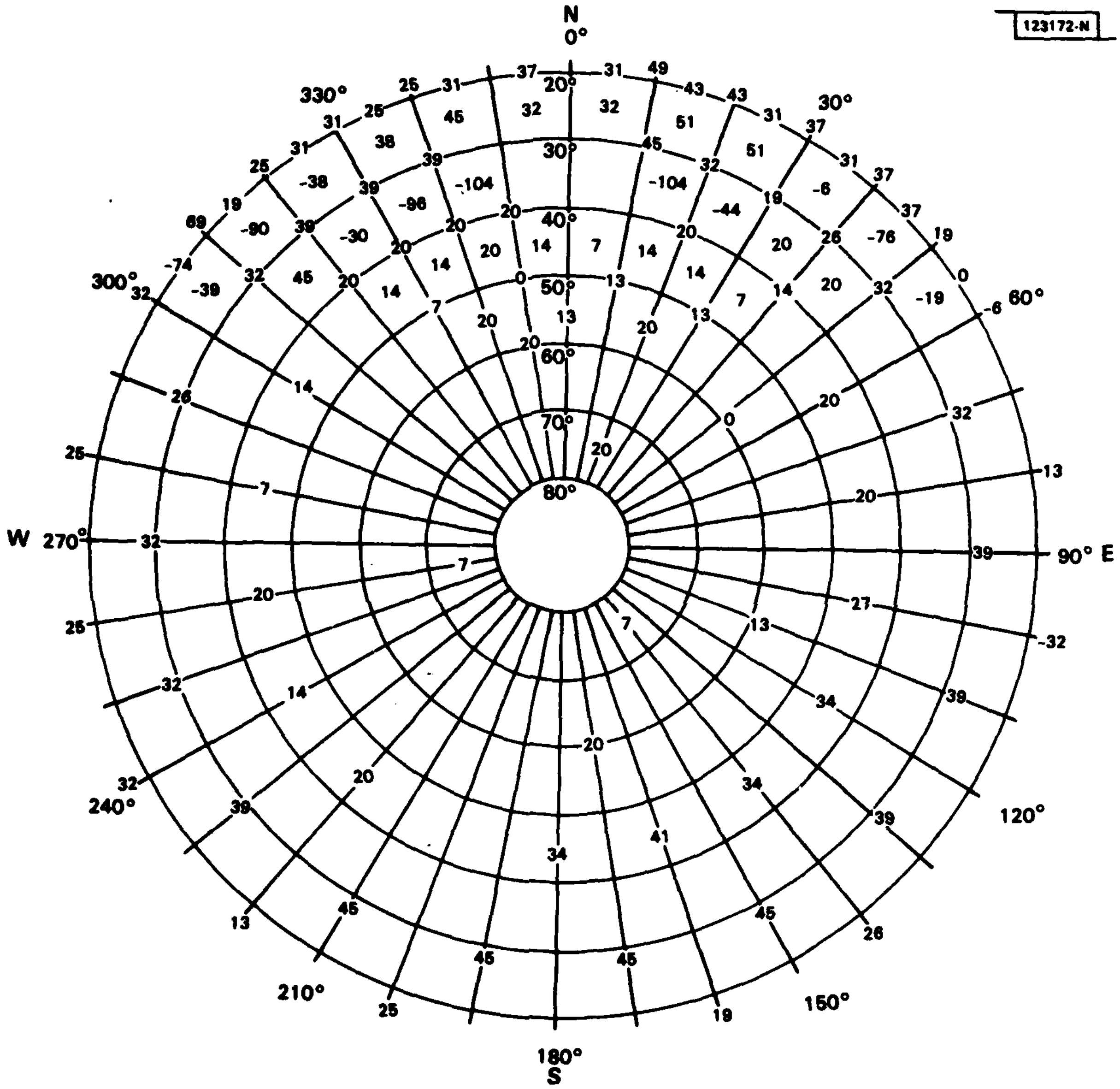


Fig. 8. Plot of residual pointing error due to sag and flexure on telescope A in arc seconds (declination).

V. SUMMARY

A global calibration procedure has been successfully carried out for the two telescopes at ETS. Discrete mathematical models were entered into software. Residual errors are less than one arc minute - up to three arc minutes in a narrow zone of the northern sky. The correction has remained stable after almost a year's operation.

APPENDIX A

Description and Use of Error File Generator

The binary data files read in from disk by GCTASK are generated by an off-line task called BLDCOR (for BuiLD CORrection files). The function of BLDCOR is to read an unformatted ASCII file of data from a User Source Library and properly format it for use by RTS (GCTASK and T4). In order to reduce real time overhead, all setup calculations are done in this task. A conversion from arc seconds to radians and sign change is all that is needed for declination errors. To obtain the right ascension error, the azimuth and elevation are converted to α and δ and the $\cos(\delta)$ term is divided out.

A conversion from arc seconds to radians and sign change completes the calculation. The above is repeated for each point in the 10° mesh azimuth and elevation grid. BLDCOR is a stand alone task which runs at the computer CRT terminal. To invoke the program, type /BLDCOR/E,,TM on the console teletype after a Console Interrupt. The program should respond with "ENTER FILE NAME ON USL ($$ TO ESCAPE)" at this point. It wants the name of the USL file containing the data to be processed. Entry of $$ will cause a correction value of 0.0 arc seconds to be used. After receiving the name, a new line is sent signaling the completion of uncompression into a scratch file, SCL (AD1).

The line printer will start on a 9-page summary of the data for diagnostic purposes. When that is finished, the program will display "ACTION UNLOCK DISK PROTECT SWITCH." This is necessary because it writes on a "protected" cylinder of the drive. The disk switch must be in the down or unprotected position before a response of /R is entered. After processing the error data, the program will display "ACTION LOCK DISK PROTECT SWITCH." Now the disk switch can be moved back to the center position. The correction data have been written to disk partition BDN. Another /R response will allow the program to finish and display "STOP DONE/BLDCOR /BLDCOR" on the CRT terminal. At this point, new data are on the disk in that system. The data will filter over to "B" computer (if done on "A" computer) with the next copy of the system from "A" to "B".

If any errors are discovered by the program, one of the following error messages will be output to the CRT terminal screen. However, something will be written to the disk in any case. To prevent invalid data from filtering into the system, use /A to the "UNLOCK" message and that will abort the task. The following is a partial list of the possible error messages generated by BLDCOR and a clue as to what may have caused it: "***FILE NOT FOUND -filename-***"; the named file is not on USL.

"EARLY EOF ON 9. I =NNNNN"; Less data than expected were on the file. "CUTOFF -- DC= R.FFFD-EE I=NNNN"; COS(dec) is less than some epsilon. Any other system error message may be generated on the I/O done by the program, but the Reference Manuals cover those messages in detail. One system message is very possible: "ABORT (LOK EO23)" will happen if /R is entered with the disk switch not down after the "UNLOCK" message.

The USL input file consists of one header line and 72 data lines. The header line consists of "A" or "B" followed by a 70 character title. The title allows for dating and identifying the file. Each data line consists of nine free format integers corresponding to the error inputs for some arc from 10^o elevation to 90^o elevation. The data are in the form of two sets of 36 lines each, ordered from 10^o azimuth to 360^o azimuth. The first data set covers δ errors, the second set covers $\alpha\cos(\delta)$ errors. All input values are in arc seconds.

The data are recorded onto the disk partition in the form of two binary files separated by file marks. The first file has error data for telescope A, the second file has data for B.

The data in one file include the 70 character header, the date and time that the file was written, the telescope ID and two Real*6 arrays, each 37 x 10, containing the error correction values in radians for right ascension and declination.

A description of the Common Block used to read in corrections follows:

```
INTEGER*2 HEADER(35), WYR, WDAY, WHR, WMIN, WSEC,
#          CTELTYP, PAD(42), IDCOR
REAL*6  ERRRA,(37)ERRDEC(37,10)
COMMON /DSKBIN/ IDCOR, HEADER, WYR, WDAY, WHR, WMIN,
#       WSEC, CTELTYP, ERRRA, ERRDEC, PAD
```

where

IDCOR - Handshake flag

HEADER - A 70 character title

WYR,WDAY,WHR,WMIN,WSEC - Time and date of last write to file

CTELTYP - The telescope ID (1="A", 2="B")

ERRRA - Errors in right ascension

ERRDEC - Errors in declination

PAD= Spare room to fill out to page boundary

APPENDIX B

Errors

The following is a printout of the current observed and computed error correction values for the telescopes at the ETS.

DISK HEADER INFORMATION:
TELESCOPE CORRECTIONS FOR "A" 01/13/82
DAY = 160/1982, TIME = 16:22:24, TELESCOPE ID = 1 => A

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	10	200	-464.16	200.00
20	10	250	-499.08	275.00
30	10	280	-472.19	300.00
40	10	300	-434.52	300.00
50	10	310	-396.13	275.00
60	10	200	-231.83	100.00
70	10	0	0.00	50.00
80	10	60	-61.79	30.00
90	10	90	-90.42	100.00
100	10	100	-100.10	150.00
110	10	110	-111.89	175.00
120	10	140	-147.38	150.00
130	10	120	-132.87	150.00
140	10	100	-117.94	175.00
150	10	90	-113.79	200.00
160	10	50	-67.53	200.00
170	10	0	0.00	200.00
180	10	-100	144.43	175.00
190	10	-120	170.19	150.00
200	10	-150	202.60	125.00
210	10	-160	202.30	90.00
220	10	-160	188.70	60.00
230	10	-160	177.15	30.00
240	10	-160	168.43	0.00
250	10	-160	162.75	-75.00
260	10	-150	150.16	-80.00
270	10	-150	160.75	-95.00
280	10	-165	169.91	-110.00
290	10	-150	161.91	-130.00
300	10	-140	162.28	0.00
310	10	120	-153.34	130.00
320	10	120	-173.81	130.00
330	10	130	-219.23	130.00
340	10	120	-239.56	140.00
350	10	120	-278.49	150.00
360	10	150	-371.45	170.00

TELESCOPE CORRECTIONS FOR "A" 01/13/82

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	20	150	-530.54	190.00
20	20	170	-444.51	200.00
30	20	190	-380.58	210.00
40	20	215	-349.51	215.00
50	20	230	-318.68	215.00
60	20	-5	6.14	10.00
70	20	-2	2.25	15.00
80	20	40	-42.31	25.00
90	20	75	-76.40	70.00
100	20	95	-95.14	100.00
110	20	105	-105.31	100.00
120	20	120	-122.47	90.00
130	20	100	-105.24	125.00
140	20	75	-82.14	125.00
150	20	60	-68.64	150.00
160	20	20	-23.82	160.00
170	20	-10	12.26	150.00
180	20	-55	68.14	145.00
190	20	-80	98.08	100.00
200	20	-125	148.89	95.00
210	20	-130	148.73	50.00
220	20	-130	142.37	30.00
230	20	-135	142.07	0.00
240	20	-140	142.89	-35.00
250	20	-135	135.40	-50.00
260	20	-130	130.20	-70.00
270	20	-140	142.61	-95.00
280	20	-145	153.37	-100.00
290	20	-135	151.81	-120.00
300	20	-125	153.54	-110.00
310	20	95	-131.63	110.00
320	20	105	-170.69	115.00
330	20	110	-220.34	110.00
340	20	105	-274.55	120.00
350	20	105	-371.38	130.00
360	20	120	-502.44	160.00

TELESCOPE CORRECTIONS FOR "A" 01/13/82

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	30	95	-587.73	180.00
20	30	100	-334.94	195.00
30	30	130	-300.22	175.00
40	30	-107	191.56	-60.00
50	30	-85	126.53	-45.00
60	30	-55	71.43	-35.00
70	30	-35	41.10	-33.00
80	30	15	-16.39	-25.00
90	30	25	-26.03	-10.00
100	30	30	-30.36	20.00
110	30	30	-30.02	15.00
120	30	40	-40.13	35.00
130	30	35	-35.61	40.00
140	30	35	-36.38	50.00
150	30	25	-26.63	60.00
160	30	10	-10.90	60.00
170	30	-5	5.54	60.00
180	30	-30	33.43	50.00
190	30	-50	55.39	45.00
200	30	-70	76.30	40.00
210	30	-80	85.23	10.00
220	30	-75	77.96	0.00
230	30	-70	71.22	-25.00
240	30	-65	65.22	-38.00
250	30	-65	65.03	-65.00
260	30	-65	65.78	-75.00
270	30	-60	62.47	-95.00
280	30	-80	87.42	-90.00
290	30	-65	76.34	-110.00
300	30	-70	90.91	-125.00
310	30	-70	104.20	-140.00
320	30	-75	134.27	-150.00
330	30	150	-346.41	110.00
340	30	130	-435.42	115.00
350	30	125	-773.33	100.00
360	30	45	-675.85	110.00

TELESCOPE CORRECTIONS FOR "A" 01/13/82

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	40	-95	541.93	-70.00
20	40	-105	357.13	-55.00
30	40	-100	239.82	-53.00
40	40	-88	164.70	-44.00
50	40	-90	140.22	-42.00
60	40	-55	74.63	-30.00
70	40	-40	48.91	-25.00
80	40	-15	16.98	-20.00
90	40	5	-5.35	-7.00
100	40	20	-20.64	-5.00
110	40	25	-25.25	10.00
120	40	30	-30.02	10.00
130	40	30	-30.04	25.00
140	40	30	-30.26	25.00
150	40	25	-25.48	30.00
160	40	10	-10.30	30.00
170	40	5	-5.19	30.00
180	40	0	0.00	30.00
190	40	-20	20.77	20.00
200	40	-30	30.91	20.00
210	40	-40	40.77	3.00
220	40	-40	40.34	-15.00
230	40	-40	40.05	-30.00
240	40	-30	30.02	-42.00
250	40	-40	40.40	-55.00
260	40	-20	20.64	-70.00
270	40	-30	32.13	-85.00
280	40	-30	33.95	-80.00
290	40	-30	36.68	-95.00
300	40	-30	40.71	-110.00
310	40	-30	46.74	-130.00
320	40	-40	74.86	-130.00
330	40	-30	71.95	-140.00
340	40	-35	119.04	-135.00
350	40	-30	171.14	-135.00
360	40	-40	371.43	-70.00

TELESCOPE CORRECTIONS FOR "A" 01/13/82

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	50	-55	180.17	-45.00
20	50	-65	174.66	-45.00
30	50	-65	141.85	-40.00
40	50	-60	109.17	-30.00
50	50	-60	93.97	-20.00
60	50	-45	62.45	-20.00
70	50	-30	37.82	-20.00
80	50	-20	23.40	-15.00
90	50	3	-3.32	-5.00
100	50	10	-10.61	-3.00
110	50	20	-20.62	5.00
120	50	20	-20.26	2.00
130	50	20	-20.07	15.00
140	50	20	-20.00	15.00
150	50	20	-20.01	20.00
160	50	40	-40.11	15.00
170	50	20	-20.10	15.00
180	50	20	-20.12	15.00
190	50	2	-2.01	10.00
200	50	-5	5.01	5.00
210	50	-10	10.01	-10.00
220	50	-10	10.00	-25.00
230	50	-10	10.03	-30.00
240	50	-10	10.13	-40.00
250	50	-15	15.47	-50.00
260	50	-10	10.61	-60.00
270	50	-10	11.06	-60.00
280	50	-5	5.85	-75.00
290	50	0	0.00	-75.00
300	50	0	0.00	-80.00
310	50	-5	7.83	-90.00
320	50	-15	27.29	-95.00
330	50	-10	21.82	-90.00
340	50	-10	26.87	-90.00
350	50	-15	49.14	-70.00
360	50	-45	161.47	-50.00

TELESCOPE CORRECTIONS FOR "A" 01/13/82

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	60	-40	88.14	-40.00
20	60	-35	71.59	-40.00
30	60	-35	64.83	-30.00
40	60	-35	58.36	-20.00
50	60	-30	45.28	-10.00
60	60	-30	41.43	-10.00
70	60	-20	25.60	-15.00
80	60	-15	18.02	-12.00
90	60	3	-3.42	-5.00
100	60	5	-5.48	-3.00
110	60	15	-15.95	2.00
120	60	15	-15.60	2.00
130	60	15	-15.36	10.00
140	60	15	-15.21	10.00
150	60	30	-30.23	10.00
160	60	30	-30.13	10.00
170	60	45	-45.12	10.00
180	60	40	-40.09	10.00
190	60	30	-30.08	5.00
200	60	10	-10.04	-5.00
210	60	10	-10.08	-15.00
220	60	10	-10.14	-30.00
230	60	10	-10.24	-30.00
240	60	10	-10.40	-30.00
250	60	15	-15.95	-45.00
260	60	15	-16.44	-50.00
270	60	15	-17.12	-55.00
280	60	15	-18.02	-60.00
290	60	15	-19.20	-65.00
300	60	15	-20.72	-60.00
310	60	15	-22.64	-70.00
320	60	10	-16.67	-75.00
330	60	5	-9.26	-70.00
340	60	2	-4.09	-65.00
350	60	0	0.00	-60.00
360	60	-20	45.33	-45.00

TELESCOPE CORRECTIONS FOR "A" 01/13/82

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	70	-30	50.32	-30.00
20	70	-20	32.62	-30.00
30	70	-20	31.29	-20.00
40	70	-20	29.77	-15.00
50	70	-15	21.17	-5.00
60	70	-15	20.09	-5.00
70	70	-10	12.75	-10.00
80	70	-10	12.19	-10.00
90	70	3	-3.52	-5.00
100	70	5	-5.68	-2.00
110	70	10	-11.05	1.00
120	70	10	-10.82	2.00
130	70	10	-10.63	5.00
140	70	10	-10.50	5.00
150	70	30	-31.22	5.00
160	70	20	-20.69	5.00
170	70	20	-20.62	5.00
180	70	20	-20.60	5.00
190	70	20	-20.62	5.00
200	70	15	-15.52	-5.00
210	70	5	-5.20	-10.00
220	70	5	-5.25	-15.00
230	70	5	-5.32	-20.00
240	70	5	-5.41	-20.00
250	70	25	-27.63	-40.00
260	70	20	-22.71	-40.00
270	70	10	-11.73	-40.00
280	70	10	-12.19	-45.00
290	70	10	-12.75	-50.00
300	70	10	-13.39	-50.00
310	70	10	-14.11	-50.00
320	70	5	-7.44	-50.00
330	70	5	-7.82	-45.00
340	70	2	-3.26	-40.00
350	70	0	0.00	-30.00
360	70	-10	16.94	-40.00

TELESCOPE CORRECTIONS FOR "A" 01/13/82

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	80	-15	20.73	-20.00
20	80	-10	13.70	-20.00
30	80	-10	13.52	-10.00
40	80	-10	13.29	-10.00
50	80	-5	6.51	-3.00
60	80	-5	6.37	-3.00
70	80	-5	6.24	-5.00
80	80	-5	6.10	-5.00
90	80	2	-2.39	-3.00
100	80	2	-2.35	0.00
110	80	5	-5.77	1.00
120	80	5	-5.69	1.00
130	80	5	-5.62	2.00
140	80	5	-5.56	2.00
150	80	15	-16.56	2.00
160	80	10	-10.98	2.00
170	80	10	-10.94	2.00
180	80	10	-10.93	2.00
190	80	10	-10.94	3.00
200	80	5	-5.49	-2.00
210	80	2	-2.21	-5.00
220	80	2	-2.22	-10.00
230	80	2	-2.25	-10.00
240	80	2	-2.27	-10.00
250	80	10	-11.54	-20.00
260	80	10	-11.73	-20.00
270	80	5	-5.98	-20.00
280	80	5	-6.10	-20.00
290	80	5	-6.24	-25.00
300	80	5	-6.37	-25.00
310	80	5	-5.51	-25.00
320	80	3	-3.99	-25.00
330	80	0	0.00	-25.00
340	80	0	0.00	-20.00
350	80	0	0.00	-20.00
360	80	-5	6.93	-15.00

TELESCOPE CORRECTIONS FOR "A" 01/13/82

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	90	0	0.00	0.00
20	90	0	0.00	0.00
30	90	0	0.00	0.00
40	90	0	0.00	0.00
50	90	0	0.00	0.00
60	90	0	0.00	0.00
70	90	0	0.00	0.00
80	90	0	0.00	0.00
90	90	0	0.00	0.00
100	90	0	0.00	0.00
110	90	0	0.00	0.00
120	90	0	0.00	0.00
130	90	0	0.00	0.00
140	90	0	0.00	0.00
150	90	0	0.00	0.00
160	90	0	0.00	0.00
170	90	0	0.00	0.00
180	90	0	0.00	0.00
190	90	0	0.00	0.00
200	90	0	0.00	0.00
210	90	0	0.00	0.00
220	90	0	0.00	0.00
230	90	0	0.00	0.00
240	90	0	0.00	0.00
250	90	0	0.00	0.00
260	90	0	0.00	0.00
270	90	0	0.00	0.00
280	90	0	0.00	0.00
290	90	0	0.00	0.00
300	90	0	0.00	0.00
310	90	0	0.00	0.00
320	90	0	0.00	0.00
330	90	0	0.00	0.00
340	90	0	0.00	0.00
350	90	0	0.00	0.00
360	90	0	0.00	0.00

DISK HEADER INFORMATION:
CORRECTIONS FROM "B" 9/28/81
DAY = 160/1982, TIME = 16:22:54, TELESCOPE ID = 2 => B

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	10	-300	696.23	190.00
20	10	-350	698.71	200.00
30	10	-400	674.56	210.00
40	10	-450	651.78	220.00
50	10	-500	638.92	230.00
60	10	-200	231.83	10.00
70	10	-30	32.38	-50.00
80	10	-25	25.74	-70.00
90	10	0	0.00	-50.00
100	10	18	-18.02	-10.00
110	10	66	-67.14	30.00
120	10	105	-110.53	80.00
130	10	130	-143.94	110.00
140	10	160	-188.70	130.00
150	10	170	-214.94	160.00
160	10	180	-243.12	200.00
170	10	160	-226.92	220.00
180	10	130	-187.76	230.00
190	10	80	-113.46	250.00
200	10	50	-67.53	270.00
210	10	-50	63.22	220.00
220	10	-125	147.42	190.00
230	10	-150	166.08	160.00
240	10	-200	210.54	140.00
250	10	-220	223.79	100.00
260	10	-240	240.25	60.00
270	10	-220	221.03	37.00
280	10	-200	205.95	16.00
290	10	-175	188.90	0.00
300	10	-150	173.88	100.00
310	10	-600	766.71	280.00
320	10	-500	724.20	280.00
330	10	-450	758.88	270.00
340	10	-400	798.52	260.00
350	10	-400	928.31	240.00
360	10	-300	742.88	210.00

CORRECTIONS FROM "B" 9/28/81

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	20	-286	1011.56	158.00
20	20	-336	878.55	151.00
30	20	-389	779.19	158.00
40	20	-430	699.01	167.00
50	20	-480	665.07	175.00
60	20	-30	36.85	-90.00
70	20	-25	28.11	-77.00
80	20	-19	20.10	-65.00
90	20	0	0.00	-39.00
100	20	23	-23.03	-11.00
110	20	54	-54.16	27.00
120	20	85	-86.75	65.00
130	20	110	-115.76	105.00
140	20	135	-147.85	120.00
150	20	113	-129.28	148.00
160	20	154	-183.43	177.00
170	20	126	-154.47	191.00
180	20	98	-121.42	205.00
190	20	50	-61.30	227.00
200	20	3	-3.57	250.00
210	20	-48	54.91	208.00
220	20	-100	109.52	166.00
230	20	-134	141.01	143.00
240	20	-169	172.48	120.00
250	20	-180	180.53	86.00
260	20	-192	192.29	53.00
270	20	-178	181.32	34.00
280	20	-165	174.53	14.00
290	20	-138	155.18	-1.00
300	20	-112	137.57	-16.00
310	20	-547	757.91	261.00
320	20	-477	775.42	250.00
330	20	-405	811.24	231.00
340	20	-341	891.63	227.00
350	20	-300	1061.08	206.00
360	20	-254	1063.49	178.00

CORRECTIONS FROM "B" 9/28/81

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	30	-250	1546.65	115.00
20	30	-304	1018.20	115.00
30	30	-10	23.09	-130.00
40	30	26	-46.55	-130.00
50	30	-9	13.40	-130.00
60	30	-11	14.29	-108.00
70	30	-13	15.27	-85.00
80	30	-1	1.09	-61.00
90	30	12	-12.49	-37.00
100	30	25	-25.30	-12.00
110	30	39	-39.02	14.00
120	30	61	-61.20	57.00
130	30	82	-83.43	100.00
140	30	93	-96.67	115.00
150	30	60	-63.92	139.00
160	30	104	-113.36	155.00
170	30	95	-105.24	172.00
180	30	58	-64.63	177.00
190	30	21	-23.26	181.00
200	30	-10	10.90	170.00
210	30	-40	42.61	155.00
220	30	-73	75.88	141.00
230	30	-106	107.85	127.00
240	30	-122	122.41	98.00
250	30	-138	138.07	70.00
260	30	-136	137.63	52.00
270	30	-135	140.55	33.00
280	30	-132	133.32	12.00
290	30	-110	129.18	-6.00
300	30	-88	114.28	-21.00
310	30	-17	25.31	-37.00
320	30	31	-55.50	-52.00
330	30	-371	856.78	218.00
340	30	-304	1018.20	205.00
350	30	-200	1237.32	160.00
360	30	-225	3379.09	130.00

CORRECTIONS FROM "B" 9/28/81

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	40	100	-570.46	-140.00
20	40	76	-258.50	-155.00
30	40	39	-93.53	-139.00
40	40	17	-31.82	-121.00
50	40	-15	23.37	-114.00
60	40	-27	36.64	-108.00
70	40	-28	34.24	-90.00
80	40	-29	32.82	-73.00
90	40	-14	14.99	-51.00
100	40	0	0.00	-28.00
110	40	13	-13.13	0.00
120	40	27	-27.02	28.00
130	40	39	-39.05	56.00
140	40	52	-52.44	86.00
150	40	32	-32.62	104.00
160	40	69	-71.08	123.00
170	40	48	-49.84	135.00
180	40	26	-27.07	145.00
190	40	2	-2.08	142.00
200	40	-14	14.42	138.00
210	40	-35	35.67	128.00
220	40	-56	56.48	119.00
230	40	-73	73.10	100.00
240	40	-91	91.07	81.00
250	40	-92	92.92	61.00
260	40	-92	94.95	41.00
270	40	-82	87.81	28.00
280	40	-72	81.49	16.00
290	40	-52	63.58	2.00
300	40	-32	43.42	-12.00
310	40	2	-3.12	-26.00
320	40	35	-65.50	-41.00
330	40	75	-179.87	-58.00
340	40	117	-397.95	-66.00
350	40	150	-855.70	-88.00
360	40	100	-928.61	-100.00

CORRECTIONS FROM "B" 9/28/81

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	50	86	-281.72	-109.00
20	50	47	-126.29	-110.00
30	50	8	-17.46	-112.00
40	50	2	-3.64	-101.00
50	50	-20	31.32	-90.00
60	50	-40	55.51	-91.00
70	50	-45	56.73	-74.00
80	50	-50	58.50	-62.00
90	50	-35	38.69	-44.00
100	50	-20	21.22	-27.00
110	50	-5	5.16	-11.00
120	50	5	-5.06	6.00
130	50	16	-16.06	28.00
140	50	26	-26.00	50.00
150	50	5	-5.00	64.00
160	50	38	-38.11	78.00
170	50	26	-26.13	91.00
180	50	14	-14.08	100.00
190	50	0	0.00	110.00
200	50	-15	15.04	110.00
210	50	-29	29.02	110.00
220	50	-40	40.01	95.00
230	50	-52	52.18	79.00
240	50	-56	56.72	65.00
250	50	-60	61.87	50.00
260	50	-64	67.89	34.00
270	50	-48	53.06	23.00
280	50	-32	37.44	10.00
290	50	-16	20.17	3.00
300	50	0	0.00	-4.00
310	50	30	-46.98	-12.00
320	50	60	-109.17	-20.00
330	50	88	-192.04	-28.00
340	50	109	-292.90	-55.00
350	50	130	-425.86	-59.00
360	50	108	-387.53	-84.00

CORRECTIONS FROM "B" 9/28/81

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	60	54	-118.99	-78.00
20	60	43	-87.95	-85.00
30	60	21	-38.90	-85.00
40	60	0	0.00	-85.00
50	60	-4	6.04	-85.00
60	60	-12	16.57	-74.00
70	60	-24	30.72	-62.00
80	60	-30	36.04	-50.00
90	60	-25	28.53	-38.00
100	60	-20	21.93	-25.00
110	60	-15	15.95	-12.00
120	60	-10	10.40	0.00
130	60	-5	5.12	9.00
140	60	0	0.00	19.00
150	60	-2	2.02	28.00
160	60	8	-8.03	38.00
170	60	11	-11.03	47.00
180	60	2	-2.00	48.00
190	60	-7	7.02	50.00
200	60	-15	15.06	52.00
210	60	-23	23.17	54.00
220	60	-29	29.40	56.00
230	60	-40	40.96	58.00
240	60	-41	42.64	50.00
250	60	-42	44.66	40.00
260	60	-40	43.85	30.00
270	60	-26	29.67	20.00
280	60	-14	16.82	8.00
290	60	-2	2.56	4.00
300	60	12	-16.57	-9.00
310	60	25	-37.73	-21.00
320	60	40	-66.70	-33.00
330	60	52	-96.32	-45.00
340	60	64	-130.91	-55.00
350	60	76	-167.46	-64.00
360	60	65	-147.32	-71.00

CORRECTIONS FROM "B" 9/28/81

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	70	38	-63.74	-56.00
20	70	35	-57.09	-59.00
30	70	25	-39.11	-58.00
40	70	17	-25.30	-58.00
50	70	8	-11.29	-58.00
60	70	0	0.00	-54.00
70	70	-4	5.10	-50.00
80	70	-8	9.76	-35.00
90	70	-12	14.08	-26.00
100	70	-11	12.49	-17.00
110	70	-9	9.95	-9.00
120	70	-7	7.57	0.00
130	70	-5	5.32	6.00
140	70	-4	4.20	12.00
150	70	-7	7.28	17.00
160	70	0	0.00	23.00
170	70	-3	3.09	26.00
180	70	-6	6.18	28.00
190	70	-8	8.25	31.00
200	70	-12	12.41	34.00
210	70	-16	16.65	35.00
220	70	-19	19.95	36.00
230	70	-23	24.46	35.00
240	70	-26	28.12	34.00
250	70	-26	28.74	25.00
260	70	-25	28.39	15.00
270	70	-18	21.12	10.00
280	70	-11	13.41	4.00
290	70	-5	6.37	0.00
300	70	0	0.00	-8.00
310	70	10	-14.11	-15.00
320	70	20	-29.77	-23.00
330	70	28	-43.81	-31.00
340	70	36	-58.72	-39.00
350	70	44	-73.80	-50.00
360	70	41	-69.45	-53.00

CORRECTIONS FROM "B" 9/28/81

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	80	14	-19.35	-31.00
20	80	17	-23.29	-34.00
30	80	14	-18.93	-37.00
40	80	12	-15.95	-34.00
50	80	10	-13.03	-31.00
60	80	8	-10.20	-28.00
70	80	6	-7.48	-25.00
80	80	2	-2.44	-20.00
90	80	0	0.00	-15.00
100	80	-1	1.17	-10.00
110	80	-3	3.46	-5.00
120	80	-5	5.69	0.00
130	80	-6	6.74	2.00
140	80	-7	7.78	4.00
150	80	0	0.00	6.00
160	80	-7	7.68	8.00
170	80	-8	8.75	10.00
180	80	-9	9.84	12.00
190	80	-9	9.85	14.00
200	80	-10	10.98	17.00
210	80	-10	11.04	18.00
220	80	-11	12.23	19.00
230	80	-11	12.36	18.00
240	80	-11	12.51	17.00
250	80	-12	13.84	12.00
260	80	-12	14.08	8.00
270	80	-10	11.96	4.00
280	80	-8	9.76	0.00
290	80	-6	7.48	-3.00
300	80	-3	3.82	-7.00
310	80	0	0.00	-10.00
320	80	2	-2.66	-13.00
330	80	6	-8.11	-17.00
340	80	8	-10.96	-21.00
350	80	9	-12.44	-25.00
360	80	10	-13.86	-28.00

CORRECTIONS FROM "B" 9/28/81

AZIMUTH DEGREES	ELEVATION DEGREES	RA*COS(DEC) INPUT ARCSECONDS	RA ERROR ARCSECONDS	DEC ERROR ARCSECONDS
10	90	0	0.00	0.00
20	90	0	0.00	0.00
30	90	0	0.00	0.00
40	90	0	0.00	0.00
50	90	0	0.00	0.00
60	90	0	0.00	0.00
70	90	0	0.00	0.00
80	90	0	0.00	0.00
90	90	0	0.00	0.00
100	90	0	0.00	0.00
110	90	0	0.00	0.00
120	90	0	0.00	0.00
130	90	0	0.00	0.00
140	90	0	0.00	0.00
150	90	0	0.00	0.00
160	90	0	0.00	0.00
170	90	0	0.00	0.00
180	90	0	0.00	0.00
190	90	0	0.00	0.00
200	90	0	0.00	0.00
210	90	0	0.00	0.00
220	90	0	0.00	0.00
230	90	0	0.00	0.00
240	90	0	0.00	0.00
250	90	0	0.00	0.00
260	90	0	0.00	0.00
270	90	0	0.00	0.00
280	90	0	0.00	0.00
290	90	0	0.00	0.00
300	90	0	0.00	0.00
310	90	0	0.00	0.00
320	90	0	0.00	0.00
330	90	0	0.00	0.00
340	90	0	0.00	0.00
350	90	0	0.00	0.00
360	90	0	0.00	0.00

REFERENCES

1. L. G. Taff and I. M. Poirier, "The Current State of GEODSS Astrometry," Project Report ETS-30, Lincoln Laboratory, M. I. T. (27 January 1978), DDC AD-A053248.

2. A. A. Mathiasen and R. D. Calvery, "Telescope Operating System," Project Report ETS-56, Lincoln Laboratory, M. I. T. (30 December 1980).

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER ESD-TR-82-095	2. GOVT ACCESSION NO. AD-A123252	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A Global Calibration Technique in use at the ETS		5. TYPE OF REPORT & PERIOD COVERED Project Report
		6. PERFORMING ORG. REPORT NUMBER Project Report ETS-66
7. AUTHOR(s) Richard C. Ramsey, Joseph H. Dial, Arthur A. Mathiasen, Robert L. Irelan		8. CONTRACT OR GRANT NUMBER(s) F19628-80-C-0002
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lincoln Laboratory, M.I.T. P.O. Box 73 Lexington, MA 02173-0073		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element Nos. 63428F and 12424F Project Nos. 2698 and 2295
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Systems Command, USAF Andrews AFB Washington, DC 20331		12. REPORT DATE 8 November 1982
		13. NUMBER OF PAGES 52
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Electronic Systems Division Hanscom AFB, MA 01731		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

global calibration, sag and flexure, astronomical refraction, telescope, pointing accuracy, modeling

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the installation and results of a global calibration program introduced for both telescopes at the Lincoln Laboratory Experimental Test Site. The uncorrected positional pointing errors, due primarily to tube flexure, sag and astronomical refraction, were found to be as high as ten arc minutes at low (twenty degrees) elevation angles. The calibration is performed by a software program which contains look-up tables, for each telescope, that represent ten-degree increments of azimuth and elevation. Residual errors are now less than one arc minute except for a narrow sone across the nothern sky. This is a region where there was a high gradient in the uncorrected errors and the residuals here, after correction, are a maximum of three arc minutes. This technique has remained stable over the past year.

DD FORM 1473 1 Jan 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

END

FILMED

2-83

DTIC